Feasibility studies of femtoscopic measurements in MPD.*

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Femtoscopy is one of the methods used in high energy physics. This technique is used to measure the size of the source created as a result of heavy ions collision. By using Monte Carlo (MC) simulations it is possible to estimate the precision of such measurements. This paper discusses estimation of the precision of the femtoscopic measurements in the MPD experiment by using MC data.

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1. Introduction

The NICA (Nuclotron-based Ion Collider fAcility) accelerator allows to perform the collisions of gold ions at energy range $\sqrt{s_{NN}}$=4-11 GeV. The MPD (Multi Purpose Detector) is one of the planned experiments at the NICA complex.

The structure of MPD is very similar to the structure of ALICE and STAR detectors [1, 2, 3]. All those experiments use TPC (Time Projection Chamber) detector as main tool for tracking, TOF (Time Of Flight) is used to improve identification of particles registered by TPC.
Femtoscopic analyses require precise measurements of identified particles with small relative momenta. ALICE and STAR collaborations studied the impact of the limited detector performance on such measurements. Additional criteria of pair selection were used to remove (or at least reduce) splitting (reconstruction of a particle incorrectly as a pair of trajectories) and merging (reconstruction of pair of particles a single trajectory) effects [4]. Procedures used by both collaborations were used in this work.

2. Femtoscopy

Femtoscopy uses correlations between particles to measure the size of the source that emits particles. There are two sources of these correlations:

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Quantum Statistical (QS) effects and Final State Interactions (FSI).The main tool of femtoscopy is Correlation Function (CF). Measured correlation function is usually fitted by formula 1.

$$CF(q) = N(1 + R(q, R)) \tag{1}$$

In the 1 factor N represents the normalization factor. R(q,R) describes part of function that is defined by two-particle correlations and interactions, this carries information about size of the measured source [5]. For Gaussian source and pairs of identical, non-interacting pions, the R(q,R) is equal to $\lambda e^{-q^2R^2}$ where λ is a fraction of correlated pairs, and R is the radius of the source. In experiment the shape of the function might be modified by detector effects.

3. Data and data selection

To estimate the precision of measurements in MPD the MC data were used. First step was to generate the sample of the central Au+Au collisions in UrQMD at $\sqrt{s_{NN}}$=11 GeV. These data were used to simulate the response of the detector by using MpdROOT framework. NicaFemto package was used to analyze data. Approximately 3.5 millions of events with centrality 0-5% were analyzed. It was required that collisions always took place in the center of the detector.

The criteria of data selection are presented in tab. 1. Information about ionization energy loss ($n_{\sigma\pi}$ cut) in TPC was used to identify particles with momentum smaller than 0.5 GeV/c, for particles with larger momentum additional cut is used (m^2_{TOF}).

Three pair cuts were used. First cut is Fraction of Shared Hits (FSH) in TPC detector. Second cut is defined as $\Delta DCA_Z = |DCA_{Z1} - DCA_{Z2}|$ where DCA_Z is Z-component of the Distance of Closest Approach (for first and second particle respectively). The ΔTCP_{ENT} is distance between trajectories of particles entering the TPC detector.

For optimization of cuts CF without femtoscopic correlations was used. Such function after normalization should be equal to one (this is the shape of the CF calculated directly from UrQMD model). Data without any pair cuts show presence of strong merging effect. Pair cuts were used to remove merging and splitting. However after using such optimized pair cuts, CF still is not flat, this problem is visible in Fig. 1, where C_{BCKG} represents CF without femtoscopic correlations. Further studies show that increased value of the CF is not a splitting effect. The "non-flatness" of the CF is stronger for pairs with larger transverse momentum.

Particle cuts	
$n_{\sigma\pi}$	$\leq$ 2 cm
$N_{TPC\ HITS}$	$\geq$ 30
DCA_{XY}	$\leq$ 1.25 cm
DCA_Z	$\leq$ 0.75 cm
m^2_{TOF}	-0.3-0.15 GeV^2/c^4
Pair cuts	
FSH	0
ΔDCA_Z	$\leq$ 0-0.4 cm
ΔTCP_{ENT}	$\geq$ 2 cm

Table 1. Cuts used in analysis.

uncertainty source	$\Delta R\%$	$\Delta\lambda\%$
particle identification	0.04-1.70	3.24-7.38
momentum resolution	1.63-1.70	5.31-2.72
fit range	3.04-8.32	2.33-9.46
background correction	5.06-45.76	16.69-57.56
track, pair cuts	1.06-5.09	7.02-23.27
total (quad. sum)	6.21-48.85	19.29-63.29

Table 2. Systematic uncertainties of femtoscopic measurements. First value corresponds to $0.1 < k_T < 0.2$ GeV/c, second for $0.4 < k_T < 1$ GeV/c.

3.1. Femtoscopic analysis

One dimensional CFs of positive pions were analyzed. The two-particle detector's effects were taken into account by multiplication of fitting function by "background function" (F_{BCKG} in Fig. 1).
In simulations it was assumed that source has three-dimensional Gaussian shape [5] , parameters of this shape were taken from most central STAR data at $\sqrt{s_{NN}}$=11.5 GeV [4]. Statistical uncertainties were negligible. One dimensional function was fitted by using model function from MC. Main source of uncertainties were: background correction and fit range. Because only central events with fixed vertex were analyzed, contribution of event cuts to the systematic uncertainties was not estimated. Uncertainties are listed in table 2.

3.2. Summary

The estimation of precision of the femtoscopic measurements of pions in MPD was presented. Further studies require taking into account uncertainties related with event selection. This work also shows that there is a problem with reconstruction of particles with relatively small momenta that

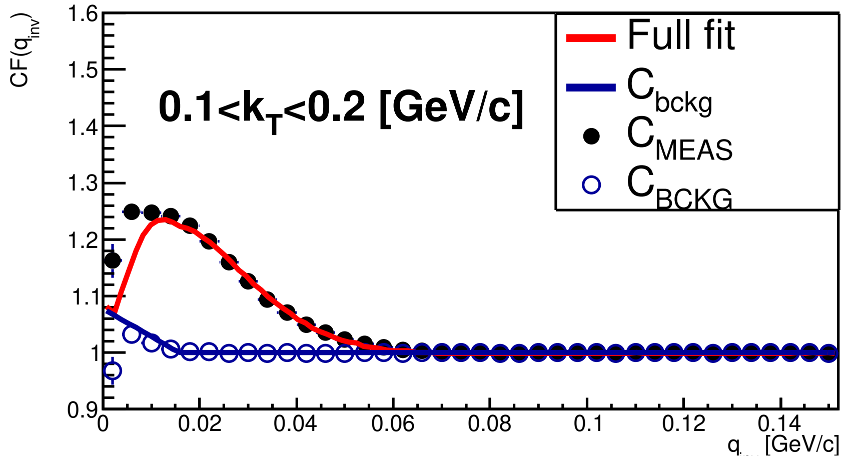

Fig. 1. Correlation function (black) with fit (red). Open circles represents CF without femtoscopic correlations. It can be noticed that "background function" (blue) doesn't describe well detector effects (open circles).

cannot be removed by known cuts. This problem requires further studies. Analysis used data generated by relatively old algorithms from 2018, there are plans to use newer algorithms with larger data sample. The framework for analysis was tested, currently the development of NicaFemto is focused on fitting three dimensional correlation functions.

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